III.1 Hydrogen Delivery Infrastructure Analysis

Marianne Mintz
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439
Phone: (630) 252-5627; Fax: (630) 252-3443
E-mail: mmintz@anl.gov

DOE Technology Development Manager:
Monterey Gardiner
Phone: (202) 586-1758; Fax: 202-586-9811
E-mail: Monterey.Gardiner@ee.doe.gov

Partners:
- National Renewable Energy Laboratory (NREL), Golden, CO
- Pacific Northwest National Laboratory (PNNL), Richland, WA

Objectives

- Refine technical and cost data in the Hydrogen Delivery Scenario Analysis Model (HDSAM) to incorporate additional industry input and evolving technology improvements.
- Expand the model to include advanced technologies and other pathway options leading to new versions of the models.
- Improve methodologies for estimating key aspects of delivery system operation and optimizing cost and performance parameters.
- Explore options to reduce hydrogen delivery cost, including higher pressure and/or lower temperature gases, and operating strategies.
- Provide analyses to support recommended hydrogen delivery strategies for initial and long-term use of hydrogen as a major energy carrier.

Technical Barriers

This project directly addresses Technical Barrier A (which implicitly includes Barriers B through F, H and J) of the Delivery Technical Plan in the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan. These are:

(A) Lack of Hydrogen/Carrier and Infrastructure Options Analysis
(B) Reliability and Cost of Hydrogen Compression
(C) Cost and Efficiency of Hydrogen Liquefaction
(D) Cost of Pipelines
(E) Cost of Solid and Liquid Carrier Systems
(F) Cost of Gaseous Storage and Tube Trailer Delivery
(H) Geologic Storage
(J) Refueling Site/Terminal Operations

Technical Targets

The project is developing a computer model to evaluate alternative delivery infrastructure systems. Insights from the model are being used to help identify an optimized delivery system which meets the long-term DOE delivery cost target of <$1.00/gge, including the cost of hydrogen conditioning, purification, transport and operations at the fueling site.

Accomplishments

- Added three new delivery pathways – involving high-pressure gaseous tube trailers, 700 bar gaseous hydrogen dispensing and cryo-compressed dispensing – to the HDSAM.
- Characterized two different station configurations (a high-pressure cascade system or a lower pressure cascade system with dedicated boost compressors for each hose) for 700 bar dispensing and developed a graphical user interface (GUI) to permit users to select a preferred configuration.
- Examined the relationship between peak demand for hydrogen and delivery cost. Explored scenarios involving “flatter” demand profiles.
- Further improved techniques for sizing pathway components and for optimizing compression and storage at the fuel station.
- Examined data on the purity of delivered hydrogen and the limits of existing test methods. Reviewed progress on developing improved test methods and developed an initial estimate of the cost impact of on-site pressure swing adsorption polishing.
- Revised station footprints to better reflect minimum separation distances between different components.
- Completed an updated and expanded version (V 2.1) of HDSAM and an associated Users’ Guide for posting on the DOE Web site.

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Introduction

As part of the H2A project, which was initiated in 2003, Version 1.0 of HDSAM was released on the H2A Web site in April 2006 following extensive beta testing and peer review. HDSAM is an Excel-based tool that uses a design calculation approach to estimate the contribution of individual components of delivery infrastructure to hydrogen cost. Each of those components is described in an individual spreadsheet or tab. The model links the individual components in a systematic market setting to develop capacity/flow parameters for a complete hydrogen delivery infrastructure. Using that systems level perspective, HDSAM calculates full, levelized cost (i.e., summed across all components) of hydrogen delivery, accounting for losses and tradeoffs among the various component costs. A GUI permits users to specify a scenario of interest. A detailed User's Guide and access to the DOE help desk also assist users in running HDSAM.

HDSAM Version 2.0 was released in May 2008. Since then, work has continued on expanding pathways; updating the data base to reflect new analyses, technologies and operating data; and using the model to examine alternative delivery strategies.

Results

In Fiscal Year 2009 HDSAM was augmented with several additional pathways and user options. Three completely new pathways were added to the model: (a) high-pressure gaseous delivery (GH2), (b) 700 bar compressed hydrogen (CH2) dispensing with liquid or gaseous delivery, and (c) cryo-compressed hydrogen (cCH2) dispensing with liquid hydrogen (LH2) delivery.

- For high-pressure gaseous delivery, a $350,000 7,000 psi (480 bar) compressed gas tube trailer with 700 kg usable capacity is characterized.
- For 700-bar refueling, two station configurations are defined – a high pressure cascade system or a lower pressure cascade system with dedicated boost compressors. Figure 1 shows these options. For the high pressure cascade option, key assumptions include refrigeration to -40°C between the boost compressor and the dispenser, a refrigeration requirement of 15 ton for a 1,000 kg/d station at a cost of $6,000/ton, and cascade storage at $1,450/kg (uninstalled). For the booster compression configuration, key assumptions include the same refrigeration requirements and one booster compressor per hose at an uninstalled unit cost of $167,000. For either configuration, gaseous hydrogen can be delivered from a centralized production location or terminal via pipeline or tube trailer.
- For the cCH2 pathway, LH2 is delivered via cryogenic tanker truck, stored as a liquid, and dispensed at 250-350 bar. Cryo-pumps, with a capacity of 100 kg/hr at 350 bar, are assumed to cost $260,000 uninstalled.

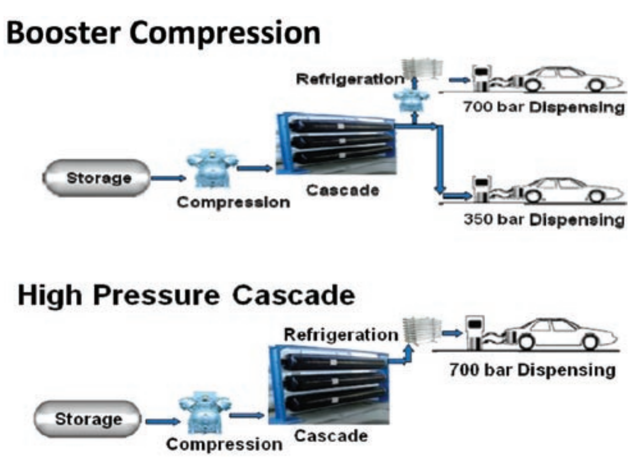

FIGURE 1. HDSAM Characterizes Two 700 Bar Hydrogen Fuel Station Configurations

The enhanced model was used to investigate alternative technologies, equipment configurations and operating regimes. The delivery infrastructure team (Argonne, NREL and PNNL) contributed advice and assistance on model logic, data and quality assurance. Model updates also underwent an extensive peer-review process within the broader hydrogen modeling community.

As shown in Figure 2, the cost of hydrogen delivery (in $/kg) varies both with pathway and with station configuration. LH2 delivery drops with cCH2 dispensing since it uses a cryo-pump in lieu of an evaporator and cascade charging system. Higher pressure fueling increases both total delivery cost and the refueling station portion of that cost, especially for the booster compression configuration. The cost of pipeline delivery with 700 bar dispensing is comparable to that of LH2 delivery with cryo-compressed dispensing.

Station costs can be substantially less with cCh2 dispensing. As highlighted in Figure 3, initial capital is nearly 70 percent lower for a LH2 station with cryo-compressed dispensing than for a GH2 station using high-pressure tube storage and 700 bar dispensing.

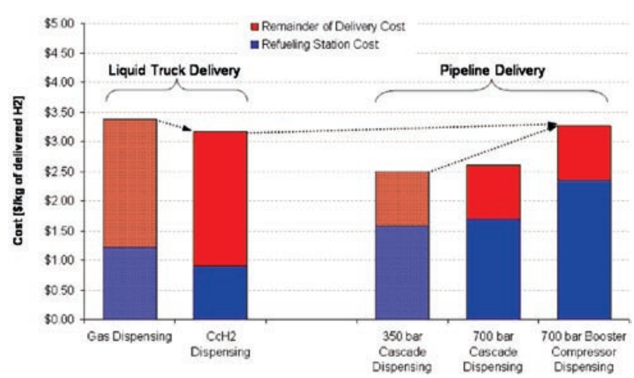

FIGURE 2. LH2 Delivery Cost Decreases with cCH2 Dispensing, Becoming Comparable to Pipeline Delivery with 700 Bar Dispensing

HDSAM also computes energy use and greenhouse gas (GHG) emissions associated with all pathways, on either a well-to-pump (WTP, i.e., including all fuels and feedstocks from hydrogen production to its dispensing onto a vehicle) or well-to-wheels (WTW, i.e., WTP, as well as to and including vehicle operation) basis. In FY 2009, energy and GHG estimation capabilities were completed for all model enhancements undertaken this year. Figure 4 displays WTW GHG emissions for several of these pathways. Note that although liquefaction is extremely energy intensive, the combination of downstream delivery and dispensing efficiencies as well as equivalent fuel production and vehicle use narrow the difference in WTW GHG emissions between LH2 and other pathways.

In FY 2009, the enhanced HDSAM was also used to investigate the impact of a number of operational and technical changes on the cost of hydrogen delivery. These included strategies to encourage a "flatter" demand for hydrogen at refueling stations, improvements in compressor reliability, and the addition of on-site polishing to bring delivered GH2 up to fuel cell specifications.

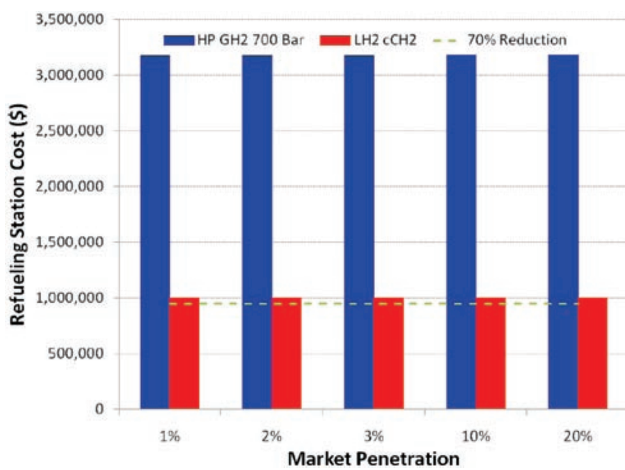

FIGURE 3. Initial Capital Can Be Reduced by Nearly 70 Percent with LH2 Delivery and cCH2 Dispensing As Compared with High Pressure GH2 Delivery and 700 Bar Dispensing

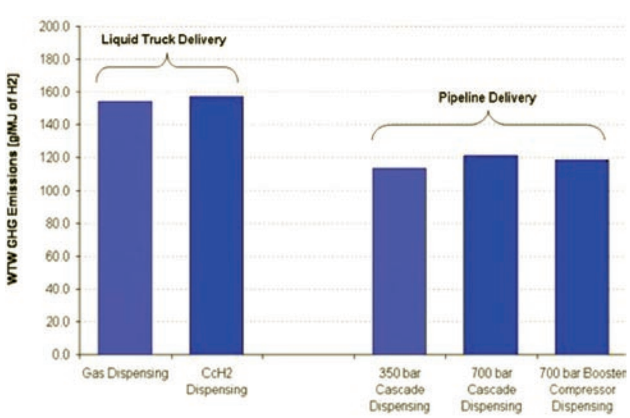

FIGURE 4. Including Hydrogen Production and Vehicle Operation, Differences in WTW Greenhouse Gas Emissions among Delivery Options Narrow

Conclusions and Future Directions

Hydrogen delivery infrastructure analysis seeks to identify aspects of hydrogen delivery that are likely to be especially costly (in capital and operating cost, energy and GHG emissions) and estimate the impact of alternative conditioning, storage and distribution options on those costs. For the Office of Hydrogen, Fuel Cells and Infrastructure Technologies (OHFCIT) this project has developed a model of hydrogen delivery systems to quantify those costs and permit analyses of alternative technologies and operating strategies. This work has been conducted collaboratively by staff of Argonne National Laboratory, NREL and PNNL with the advice and assistance of several industrial partners. Regular interaction has also occurred with OHFCHIT's Fuel Pathways and Delivery Tech Teams.

Tasks completed through June of FY 2009 have been discussed above. The following tasks will be completed by the end of FY 2009:

- The 2.1 point release of HDSAM will be completed and posted on the DOE Web site, along with a revised Users' Guide.
- In the 2.1 point release, HDSAM's capabilities will be further expanded. In addition to the expansions discussed above, V 2.1 will include a revised refueling station footprint, an additional cryo-compressed pathway, centralized production, and delivery to multiple urban areas.
- Continued interaction and collaboration among the project partners and with the Fuel Pathways Integration Tech Team, the Delivery Tech Team, and the broader hydrogen modeling community.

FY 2009 Publications/Presentations

1. Mintz, M. and A. Elgowainy, *Reducing the Cost of Hydrogen Fueling: Insights from Delivery Modeling,* National Hydrogen Association Annual Meeting, Columbia, SC, April 2, 2009.

2. Elgowainy, A., *Analysis of Hydrogen Dispensing Options Using HDSAM 2.0*, HIA/IEA Task Definition Workshop, Amsterdam, February 13, 2009.

3. Mintz, M., A. Elgowainy and M. Gardiner, *Rethinking Hydrogen Fueling: Insights from Delivery Modeling,* 88th Annual Meeting of the Transportation Research Board, Washington, D.C., January 14, 2009.